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Taking the "Guess-work" Out of Engineering Education: Establishing the Virtuous Cycle of Research

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Abstract

Challenges of the 21st Century on future engineers results in the need to transform engineering education, ie how we educate students to be engineers. The Grand Challenges of the 21st Century for engineering education identified in various reports requires graduates who can comfortably solve novel, multidisciplinary problems. In addition, today's engineering graduates are expected to not only have content knowledge, but also have professional skills, such as working in multi-disciplinary teams, deep learning, thinking and problem solving skills, communication skills, etc. The calls for major changes in engineering education results in a flurry of modifications and adaptations throughout the world, even in renowned research universities, such as the Massachusetts Institute of Technology and Harvard University in the United States. Nevertheless, these transformations can be costly, and would be futile without proper efforts to take the scholarly approach. Consequently, there are efforts to conduct rigorous research in engineering education to determine the actual problem and seek meaningful solutions that will bring significant impact, leading to the virtuous cycle of research. While there are high level of activities in engineering education research in North America and Europe with government and institutional support in the form of funding, efforts from across the globe are also flourishing, from Australia to Asia, South America and Africa. Efforts in conducting rigorous research and the collaborative network in engineering education currently taking place world-wide is discussed in this paper. The paper then focus on how to conduct engineering education research in establishing the virtuous cycle of research to attain meaningful outcomes that can enhance the quality of engineering education to produce graduates who can rise up to the challenges of the new millennium.

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1. Introduction

The 21st Century provides a myriad of challenges, such as rapid development, economic turmoil, fast-changing technological advances, energy crisis, borderless world and many more. Faced with these challenges, just as business as usual cannot work anymore, so does education as usual cannot help us produce the desired manpower and leaders.

The calls for change in engineering education have been coming from various quarters. The focus on engineering education by governments from across the world reflect just how important and valuable engineers are for the development of a nation. Engineers are regarded as the asset and wealth of a nation because they are problem solvers and innovators. For this reason, the Korean government sponsored sixty nine Centres for Innovative Engineering Education in engineering schools across the nation to enhance the quality of engineering graduates, who can fulfil the needs of the new millennium.

Change, however, must be undertaken from a scholarly, evidence-based approach. Unbridled innovations in education without properly studying their impact may actually be costly and detrimental to the quality of learning. In the ASEE report, "Innovation with Impact":

> *"the issue is not simply a need for more educational innovations. The issue is a need for more educational innovations that have a significant impact on student learning and performance, whether it is through widespread and efficient implementation of proven practices or scholarly advancements in ideas, methods or technologies."*

The history of engineering education research goes back as early as 1893 [1] by lecturers whose professional training was in an engineering discipline [2]. It evolves into a "new discipline" of its own when Prof. Dr. Kamyar Haghighi proclaimed it in 2005 and now there are doctoral programs in engineering education flourishing [3]. Purdue University is the pioneer in offering a PhD in Engineering Education under the late Prof. Haghighi. Several other universities followed suit, such as Virginia Tech and the University of Utah.

Since then, here has been a steady, growing movement towards increasing the capacity to undertake rigorous research in engineering education in North America, Europe, South Africa and Australia [4]. These movements are sometimes championed by associations, special interest groups and centres. For example, the ASEE and the National Academy of Engineering is very active in promoting rigorous research in Engineering Education in North America, the European Society on Engineering Education (SEFI) in Europe, Centre for Engineering Education Research in the University of Cape Town in South Africa, Australasian Association for Engineering Education in Australia, and Research in Engineering Education Network (REEN), which has a board member representing various regions throughout the world, for global promotion in conducting research in engineering education.

Government commitment in promoting rigorous research in Engineering Education can be seen from funding made available to train engineering educators to conduct educational research, as well as grants for academics to conduct research in engineering education. For example, since 2005, the US National Science foundation had provided millions of dollars these types of funding, with the European Union following suit. The Korean government also encourages research in engineering education through the sixty nine centres of innovative engineering education throughout Korea.

Though the move is somewhat slower in Asia, there has been interest, with discussions on forming a community of practice taking place in several workshops and conferences. The interest is especially evident in Malaysia, where there are now two PhD in Engineering Education programme - one in Universiti Teknologi Malaysia (UTM), the other in Universiti Kebangsaan Malaysia. Both universities also has a centre for engineering education. The PhD in Engineering Education programme in UTM has now managed to yield eight graduates, with more coming in the near future. The efforts to promote engineering education research in Asia is also bearing fruit, when the Centre for Engineering Education in UTM managed to win the bid to host the Research in Engineering Education Symposium, which is co-organized with REEN, in 2013. This is the first time the conference will be held outside of North America, Europe and Australia.

2. Calls for Meaningful Research in Engineering Education

The call made by National Academy of Engineering [5] and the accreditation requirements put in place by Washington Accord [6] and Engineering Accreditation Council, Board of Engineers Malaysia [7] has resulted in many engineering departments to review and change their curriculum, assessment as well as teaching and learning methods in engineering programs. However, to reform engineering education, there is a need to understand how students learn engineering [8]. These are the fundamental research in engineering education that links theories and reseaerch into practice. Through this type of research, we are able to inform or even update learning theories via rigorous [9], meaningful [10] and evidenced-based [11] research in engineering education. This in turn will influence how other researchers in engineering education in conducting their research thus improve the teaching and learning in engineering. A scholarly research may contribute to the body of knowledge in the learning sciences [2] or educational theories.

The call for meaningful research in engineering education is not new. As Watson [12] said that "Research is necessary, but without translation into changes into faculty, courses, and curriculum, it will not produce called for changes" (pg.3). By "meaningful research" we mean that the outcomes of the research can provide solutions to educational problems and bring change to the present educational settings. The research must be conducted rigorously and scientifically based on the current state of engineering education. It is necessary to conduct meaningful research in engineering education because [13]:

a. It enable us to conclude effect of changes with strong justification
b. The recommendations made for educational change are based on proper studies, not "guess work"
c. Research in different geographical areas or setting may not be generalized directly, there is a need for research to adapt the research recommendations to the local setting
d. This can eliminate or minize superficial changes with no or little benefit
e. If systematically planned, it can answer the big questions and problems in engineering education

3. Virtuos Cycle of Research

Meaningful research should be rigorous, related to the current and local practice, issues and problems as well as following up-to-date theories and literature. The outcomes of the research should be readily accepted by the local policy makers and practitioners in engineering education. The Rigorous Research in Engineering Education (RREE) project [9] has provided a clear guideline on how to produce rigorous research in engineering education which follows the NRC's guideline on scientific and rigorous research in education which are:

a. Pose significant questions that can be answered empirically
b. Link research to relevant theory
c. Use methods that permit direct investigation of the question
d. Provide a coherent and explicit chain of reasoning
e. Replicate and generalize across studies
f. Disclose research to encourage professional scrutiny and critique

The RREE approach links theory, research and practice as shown in Figure 1. The reseach must grounded in theories and use appropriate research methodology. The results must implicate the practice.

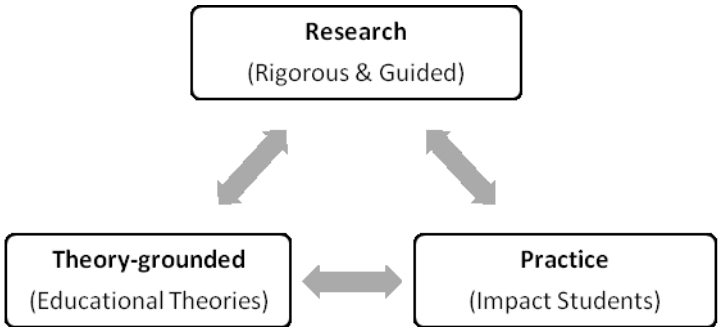

Fig.1: Framework of RREE approach

Meaningful research should also be applicable to the educational practice. This is as explained by Jameison & Lohmann [1] on the innovation cycle of educational practice and research as shown in Figure 2. The practitioners or the engineering lecturers, through their educational practice in the engineering classrooms, identify problems and issues that hinder the learning of the students. These problems and issues need to be turned into researchable questions that may lead to specifically designed engineering education research. The research should be following the RREE framework and provide answers to the research questions. The answers will become the solution to the lecturers who posed the problems initially. The findings of the research will help to improve their educational practice and thus improve the state of engineering education. This virtuous cycle will continue as more problems and issues are identified in the engineering educational practice. Rather than guessing what are the problems that students are facing in engineering classroom, this virtuous cycle of engineering education research can provide meaningful research that can be applied by engineering educators in improving their educational practice as well as for policy makers in making the correct educational decision.

Engineering educators and policy makers are constantly making educational decisions such as which teaching method should be used to teach the second law of thermodynamics, how many students are ideal for an active learning class, how best to assess students' engineering design skills, what are the training needs for a new engineering lecturer, etc. These educational decisions should not be made based on experience or guesses. The engineering educators must first search for answers from a wide literature in engineering education published especially in quality journals such as Journal of Engineering Education, IEEE Transactions on Education, International Journal of Engineering Education, and others. Then, rigorous research should be conducted by putting the above issues into researchable questions such as:

a. What are the students' learning difficulties in the topic of second law of thermodynamics?
b. Is there a significant difference in the achievement between students in a problem-based learning class and a lecturer class in learning the topic of the second law of thermodynamics?
c. What are the student perception on learning the second law of thermodynamics using cooperative learning?

By doing so, it will take out the "guess work" from making educational decisions in engineering education.

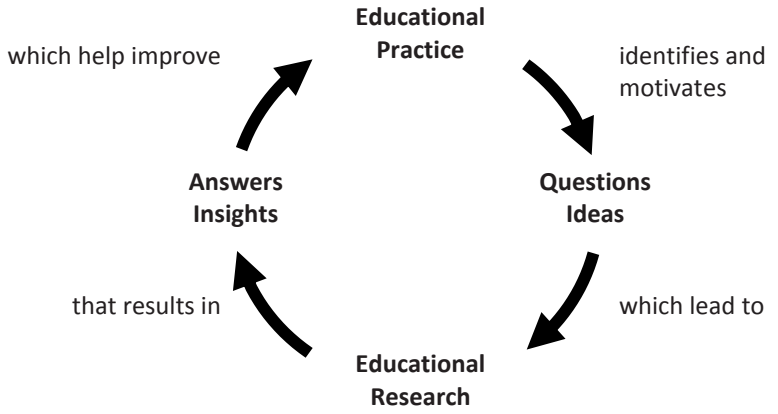

Fig.2: The innovation cycle of educational practice and research (Jameison & Lohmann, 2009; 6)

4. Conducting Research in Engineering Education

Engineering education research, like any other scientific and empirical research, is using the same scholarly research principles that include the following steps:

a. Identify the problem
b. Review literature and established theories to connect problem to grounding principles
c. Design the methodology
d. Analyze data
e. Find meaning to conclude and generalize

The purposes of conducting research are to solve problems and find answers (facts). Therefore, to begin a research project, one must first establish that there is a problem in the correct educational practice. Figure 3 can be used to guide researchers in establishing research problems. For an engineering educator or practitioner, the problem can be found from his/her current practice through experience, interest, feedback from students and colleagues, students' performance and literature (other research). This will start the virtuous cycle as suggested by Jameison & Lohmann [1] where research ideas come from the educational practice.

The second step is to formulate researchable questions to carry out rigorous research in solving the problem. In solving a problem scientifically through research, the problem needs to be identified clearly. This will take the steps of establishing the problem background, problem statement, research objectives and research questions. The relationship between these terms is as shown in Figure 4. They move from general to specific. The explanation of each terms above is as below:

a. Problem background - the general explanation of the problem
b. Problem statement – summarizes the problem background into a statement that can describe the problem specifically
c. Research objectives – targets that need to be achieved to solve the problem statement
d. Research questions – questions that need to be answered to achieve the research objectives

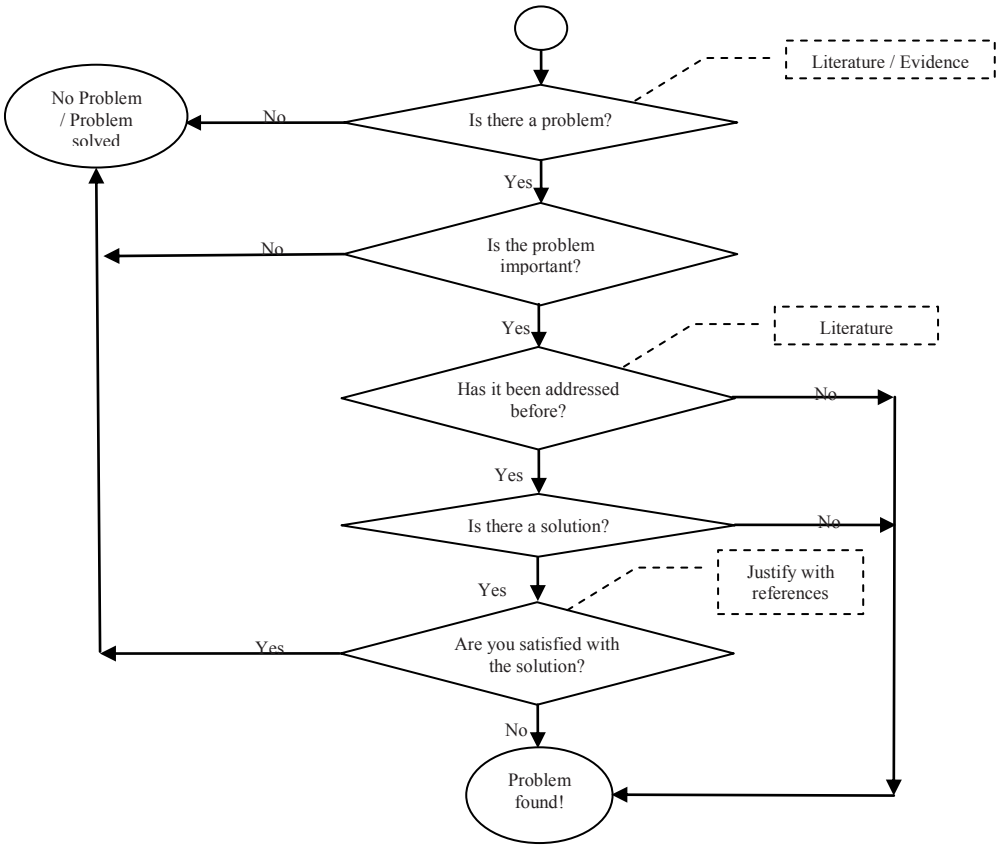

Fig. 3: Guide to establishing research problems

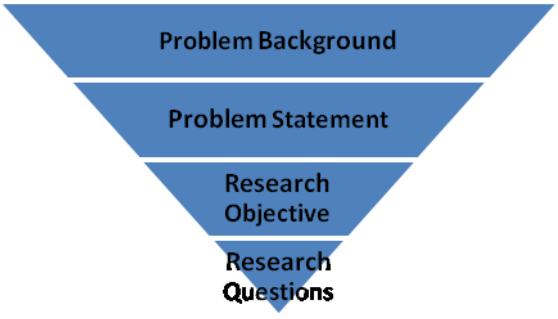

Fig.4: Relationship between problem background, problem statement, research objective and research question

There are a variety of research methodology and research methods in engineering education. [14-16] have provided a few good examples and explanation of the appropriate methodology in engineering education. Research methods are the techniques or procedures used to gather and analyse data related to some research questions or hypotheses [17]. It is different from research methodology or the strategy, plan of action, process or design lying behind the choice and use of particular methods and linking the choice and use of method to the

desired outcomes. Research methodology is a broad research design that inform how we know a phenomenon such as experimental research, survey, action research, grounded theory, ethnography and so on. Some examples of research methods are questionnaire, paper–and-pencil testing, interview, observation, document analysis, focus group discussion, thinking aloud protocol, etc.

5. Collaborative Efforts through Interdisciplinary Approach

In order to produce meaningful research, it will be difficult if engineering educators without any training in educational research are embarking their research alone. Interdisciplinary approach is a trend in engineering education. A quick survey on papers published in Journal of Engineering Education (JEE) between 2007 and 2011 reveals that out of 169 research papers and guest editorials, more than 118 papers are published by researchers / authors who have different backgrounds (based on the affiliation and authors' short biography). A paper was written by at least one engineering educator and one researcher from the social science, which may be in education, psychology, language, management and so on. The most exciting trend is that, at least 43 papers are written by researchers / authors in the specific area of engineering education.

Therefore, research collaboration between the engineering faculty and the social sciences, especially education faculty is the way forward in producing meaningful research in engineering education. The engineering faculty brings about the problems and issues in their practice. The education faculty can assist in formulating and identifying the right research questions to be investigated, suggest the appropriate research methodology and together solve the problems. When the problems are solved or recommendations are made, the engineering faculty will be able to make meaning out of the findings of the research to put into their practice. With this virtous cycle of research in engineering education, the quality of engineering education can be improved based on research, not "guess work".

For this reason, a doctoral program at Universiti Teknologi Malaysia (UTM), which is the first university in Asia that offers a PhD in Engineering Education, uses the model of joint supervision for the doctoral students where one supervisor must be from the engineering background and the other from the education background. This is to ensure that the doctoral students obtain the best out of these two experts. Such interdisciplinary approach has produced, thus far, eight PhD graduates in Engineering Education since 2007. This meaningful and scholarly research in engineering education that impact the teaching and learning of engineering students as most of the students in this doctoral program are engineering educators. They are taking the effort to master the research methodology in engineering education and solve some of the problems in their educational practice.

6. Putting Research Results into Practice

One of the best ways to produce meaningful research in engineering education is for the practitioners to become the engineering education researchers. Engineering educators who are trained to conduct engineering education research through a doctoral program in Engineering Education manage to produce meaningful research that can improve not just their own teaching but also that of their programmes. For example, a PhD level research has managed to prove that students managed to developed team based problem solving skills after undergoing a semester of Cooperative Problem Based Learning in a course. Research is currently being continued on how best to train academic staff to use the method.

Thus, an interdisciplinary approach has produced engineering education as a "new discipline". In addition, collaboration between engineering and education faculty members are showing success in producing meaningful and scholarly research in engineering education. Engineering faculty members are in a position to identify problems and issues that are significan enough to be studied. Also, it may be easier for experts in engineering education to convince their colleagues in engineering to change their teaching methods than for an expert in education to do so. On the other hand, Education faculty members are the experts in educational theories and

research methodologies. Their expertise ensures that the research and innovative approches found have strong theoretical grounding, according to the accepted principles in ensuring a scholarly and valid approach. This form of collaboration is undoubtedly a smart synergy in coming up with innovative solutions with meaningful impact in engineering education.

7. Conclusion

Engineering educators must not feel contented with the current educational practice in the engineering setting when calls for changes are echoing from different stakeholders locally and globally. As such, we, as the practitioners in engineering education, must take up the role of deciding what are the best mechanisms to better educate our students in order to fulfill the needs of the future. In making the right educational decision, we cannot make guesses and assumptions but we must make the efforts to collaborate with other researchers in carrying out meaningful research in engineering education. Any educational decision will inevitably impact the students in many ways. We only need to be certain that we have made the right decision to bring positive impacts to our students. And that certainty can only appear if we have researched it in a meaningful way.

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